Provisional Draft.]

HARVARD UNIVERSITY

OUTLINE OF REQUIREMENTS

IN

METEOROLOGY

INTENDED FOR USE IN PREPARING STUDENTS FOR HARVARD COLLEGE AND THE LAWRENCE SCIENTIFIC SCHOOL

CAMBRIDGE
1897

Provisional Draft.]

OUTLINE OF REQUIREMENTS IN METEOROLOGY.

Object of this Pamphlet. — The present outline is intended to serve as an aid to teachers who wish to prepare their pupils for the examination in Elementary Meteorology given by Harvard College and the Lawrence Scientific School. The suggestions here made will suffice to indicate the essential points which a high-school course in this subject should cover, and on which students are expected to be prepared when they come up for examination. It is not intended that this outline shall be rigidly adhered to, but that the teacher shall use his discretion in changing the order of treatment here suggested, and in extending the course as he may see fit. The outline is to be for the present considered to a large degree experimental. This must inevitably be the case until it has been tested by actual use in schools. In the light of the experience which will thus be gained, it will probably be possible shortly to publish a revised outline. Teachers are requested to communicate their views freely regarding the general scheme of the course, or concerning any of the individual subjects suggested for study.

Object of the Course. — The scheme of work here proposed corresponds quite closely to the plan followed in the course in Elementary Meteorology (Geology *B*) in Harvard College. Careful and systematic work in meteorology, of the character here indicated, will be found to give the student good training in scientific methods of investigation, and to make him to some extent a thinker and investigator on his own account. It will also furnish a basis on which later studies in more advanced meteorology may be continued. This course, however, should give so rational and systematic a knowledge of the leading facts concerning the atmosphere, the weather and its changes, and the physical laws underlying these changes, that it will afford to those who do not pursue the subject further a useful and well-rounded part of their education.

Time necessary for the course. — The course should occupy at least three hours a week, in addition to supplementary hours for study and observation, for half a school year. It is, however, recommended that the course should be extended through a whole year, at the rate of an hour and a half a week (with supplementary hours as above), in order to give opportunity for observation through autumn, winter, and spring. It may in this form be combined with a course in astronomy, which is advantageously arranged in the same manner.

The teacher's share in the work. — The work of the teacher may be indicated under the following headings: Instruction in the use of instruments; selection of subjects for observation; suggestions for keeping note-books; guidance in the discussion of observations; presentation of the larger and more general relations of the various subjects studied, such as cannot be learned without the aid of text-books or lectures. The teacher should encourage the students to discover for themselves, as far as possible, the facts and generalizations that follow from their observations. Useful practice in English composition may be had by requiring careful formulation of these results. There may be need of much assistance from the teacher at times, especially near the beginning of the course; but as the work becomes more familiar, the students should be left more and more to themselves, and the teacher should confine himself to planning the order of observations, to giving instruction in such subjects as are not illustrated by local observations, and to promoting the discussion of the results that have been obtained by the class.

The teacher's preparation for this work should include a careful study of the general subject, such as may be based upon the reference book, Davis' Elementary Meteorology, supplemented by additional reading, and by practice in the use of the ordinary meteorological instruments and in the construction and interpretation of daily weather maps.

Previous preparation of the student. — The study of geography in the grammar school or early years of the academy should have familiarized the student with the thermometer, the rain-guage, and the wind-vane, and their use in simple weather records; weather maps and their elementary interpretation; the observational determination of the variation in the sun's noon altitude and in the length

of the day and night with the seasons; and the general distribution of heat belts, prevailing winds, and rainy and dry regions over the world. If these subjects have not been previously taught, it will be impossible to present the work in meteorology as here outlined without a serious addition to the time allotted to it.

In the high school, or later years of the academy, physics and geometry should precede meteorology.

Note-Books. — Each student should keep a note-book in which careful record is made of the instruments used, of the conditions of their exposure, and of the observations made. Whenever a special problem involves the combination of records made by different observers, the source of the combined records should be clearly indicated. The records should be duly tabulated and discussed. Inferences drawn from the observations must be separately entered on pages opposite to those bearing the observations. Distinction must be made between the student's own inferences and those that have been suggested by others. Care should be given to the form of all verbal statements in which results are embodied.

The notes should not be crowded. Some space should be left between successive topics, and each topic should be marked with a prominent heading. A summary of the various topics, which will be necessarily encountered in a somewhat unsystematic order during the progress of the observational work, should be finally made according to some systematic scheme. An index should be appended.

Examination. — The candidate presenting meteorology as an admission subject will be required to take both a written and a laboratory or practical examination. The written examination may test his understanding of observational methods appropriate to the subject, but will call chiefly for a knowledge of facts and principles. The laboratory or practical examination will test his skill in observation as well as his grasp of principles. This examination can be taken in Cambridge only; for those who are examined elsewhere in June, it will be postponed to September. It may include the use of instruments, the discussion of observations, and the construction and interpretation of weather maps and climatic charts.

The candidate will be required to present at the time of the laboratory or practical examination, the original note-book in which he recorded, with dates, the steps and results of the observations which

he made at school. This book must bear the endorsement of the teacher, certifying that the notes are a true record of the pupil's work. The note-book is required as proof that the candidate has formed the habit of keeping a full and intelligible record of his work through an extended course of observational study, and that his work has been of a satisfactory character; but greater weight will be given to the practical or laboratory examination than to the note-book in determining the candidate's attainment.

This pamphlet has been prepared under the authority of the Department of Geology and Geography of Harvard University. Teachers who wish to make any suggestions or to ask any questions in regard to the work or the examination should address, —

until February 1, 1898, W. M. Davis,
after February 1, 1898, Robert DeC. Ward,
Harvard University,
Cambridge, Mass.

EQUIPMENT.

Instruments.	*Cost.*
Exposed thermometer (with brass support)	$2.50– 2.75
Maximum and minimum thermometers	7.75– 8.25
Wet and dry thermometers	5.00– 6.50
Sling psychrometer	5.00
Rain gauge	5.25
Soil thermometer	4.50–19.00
Wind vane	10.00
Anemometer	23.00–25.00
Anemometer register	24.00–35.00
Barometer (aneroid)	14.00–16.00
Barometer (mercurial)	30.00

[These instruments can all be procured of H. J. Green, 1191 Bedford Avenue, Brooklyn, N. Y.]

Thermograph (Richard Frères, Paris) . $30.00 (without duty)
Barograph (Richard Frères, Paris) . . 27.60 (without duty)

[These two instruments can be procured through Glaenzer Frères and Rheinboldt, 26 Washington Place, New York, N. Y.]

Note. — These instruments, while all desirable, are not all necessary. The sling psychrometer (which may be used as an ordinary sling thermometer), the maximum and minimum thermometers, the rain-gauge, and some form of barometer are essential. A wind vane on a neighboring building may save the

expense of buying such an instrument. The other instruments, as above suggested, should be added if possible. The instrument shelter, in which the thermometers and thermograph should be exposed, may advisably be built outside of one of the windows of the school building.

Books, etc.

Davis: Elementary Meteorology. Ginn, Boston, 1895. $2.50.

NOTE. — There is no text-book covering the course as here described, but this book will be found necessary as a reference book in the non-observational part of the work.

Instructions to Voluntary Observers.
Instructions for Use of Maximum and Minimum Thermometers.
Instructions for Use of the Rain Gauge.
Barometers and the Measurement of Atmospheric Pressure.
Instructions for Obtaining and Transcribing Records from Recording Instruments.

NOTE. — These pamphlets, all issued by the U. S. Department of Agriculture, Weather Bureau, and obtainable on application to the Chief of the Weather Bureau, Washington, D. C., will be found the best guides in making observations, the care of instruments, etc.

Daily weather maps, issued from the nearest station of the Weather Bureau, and sent free of charge to schools, are a necessary part of the equipment in this course. The Monthly Weather Review (costing 10 cents a number), the Bulletins and other publications of the Weather Bureau, which may be secured from the Chief of the Weather Bureau, as above, and the various publications of the local State Weather Services, will also prove useful.

Other publications which the teacher may find it helpful to consult are the following: —

Greely: American Weather. Dodd, Mead and Co., New York, 1888.
Scott: Elementary Meteorology. International Scientific Series, London, 1889.
Abercrombie: Weather. International Scientific Series, Appleton, N. Y., 1887.
Waldo: Elementary Meteorology. American Book Co., New York, 1897.
Russell: Meteorology. Macmillan, New York, 1895.
Hazen's Meteorological Tables. Washington, 1888.
Smithsonian Meteorological Tables. Smithsonian Institution, Washington, 189–.

OBSERVATIONS.

Observational work in meteorology should include a considerable variety of the subjects given in the list below, but it is not expected that any one scholar can accomplish all that is here outlined. Examples should be selected from the list, as opportunity offers, so that each scholar shall acquire a personal familiarity with at least fifteen problems, not less than two being taken from each of the seven headings given below.

Few of the problems here suggested call for continuous routine observation at fixed hours; they require, on the other hand, an intelligent examination of ordinary weather phenomena with special reference to discovering their explanation. In most of the problems, a small number of observations will suffice. Much time may be saved by cultivating a habit of promptly attacking the work in hand. Under the supervision of the teacher, different problems may be assigned to the several members of a class; or several scholars may work on different parts of the same problem, exchanging records in order to save time. It is expected that all the scholars will have a general knowledge of the results which have been obtained from the observations made by the other members of their class. The teacher will use his discretion in arranging the order of the problems, and in selecting those that are best suited to the season in which the work is done, to the locality in which the school is situated, and to the facilities and apparatus at command. The variety of accessible problems decreases in city schools, but much may be done there, as well as in village or country schools.

The essence of the observational work does not lie in the performance of specified tasks, rigidly defined and alike for all schools, but rather in the cultivation of a habit of scientific inquiry by the practical study of atmospheric phenomena. The real nature of these phenomena becoming known by actual observation, rapid advance may be made in knowledge concerning the distribution of similar phenomena by means of the non-observational, or text-book portion of the course. It is believed that by a judicious combination of these two kinds of study, the advantages of both may be preserved, while the disadvantages of slow progress through purely inductive work, and unsound progress through purely didactic work may be avoided.

I. TEMPERATURE.

(Instructions, 12–26. Davis, 17–42, 56–61.)*

The temperature of the air, obtained by the sling thermometer (supplemented by maximum and minimum thermometers and thermograph, if available) should be determined under a variety of conditions; for example, close to the ground, and at different heights above the ground; at different hours, day and night; in different seasons; in sunshine and shade; during wind and calms; in clear and cloudy weather, in woods and in the open; over bare ground, grass, or snow; on hills and in valleys. There should also be observations of the temperature of ground and of snow, at the surface and at slight depths beneath the surface, under different weather conditions and in different seasons.

The data thus determined will enable the student to investigate a number of problems, such as the following: —

a. The mean temperature of a day or of several days, and the variation of the mean with changes of weather and of season (Davis, 61, 62).

b. The diurnal range of temperature under different conditions and at different heights above the ground (Davis, 27, 28, 30, 42, 134, 155, 243).

c. Changes of temperature in the lower air and their control by the condition of the ground, the movement of the air, etc. (Davis, 26–28, 30–34, 316, 317.)

d. Vertical temperature gradients and inversions of temperature (Davis, 27–28, 34, 32, 138, 139, 156, 158, 243–246, 317).

e. Cyclonic and anticyclonic changes of temperature (Davis, 27, 30, 42, 134, 155, 218, 311, 333).

* These references are to "Instructions to Voluntary Observers" and to Davis' "Elementary Meteorology." The references are intended as guides for the teacher.

II. WINDS.

(Instructions, 49–54. Davis, 93–99.)

The direction and velocity (or estimated strength) of the wind should be determined at different hours, under different conditions of weather, and in different seasons. These observations will lead to the following problems: —

a. The prevailing direction and mean velocity of different periods of several days each (Davis, 98).

b. The diurnal variation of velocity in fair weather (Davis, 41, 132).

c. The variations in direction and velocity due to cyclones and anticyclones, as shown on the weather maps (Davis, 183, 215, 226–247).

d. The correlation of wind and temperature, as suggested in I, *e.*

III. HUMIDITY, DEW, AND FROST.

(Instructions, 27, 49–54, 71–80. Davis, 146–150.)

The humidity of the air, as determined by wet and dry bulb thermometers, and the occurrence or absence of dew or frost should be studied together. Observations should be made at different hours, in different kinds of weather, and in different seasons. From these, the following problems may be solved: —

a. Diurnal variation of relative humidity under different conditions (Davis, 152).

b. Relation of absolute and relative humidity to the direction of the wind, and thus to cyclones and anticyclones (Davis, 230–247).

c. The formation of dew, as dependent on the temperature and humidity of the air; the exposure and condition of the ground; and on the condition of the sky (clear, fair, or cloudy); and the vertical temperature gradient (Davis, 154–157).

d. The formation of dew as dependent on the movement of the air, and thus on cyclonic and anticyclonic controls (Davis, 154–156).

e. The formation of frost, as dependent on similar conditions; especial attention being paid to the relation of frost and inversions of temperature, and to the frequency of frost on open or sheltered surfaces, on hills or in valleys, and on the lower and upper branches of shrubs (Davis, 156–158).

IV. CLOUDS AND UPPER AIR CURRENTS.

(Instructions, 57. Davis, 119, 181–182).

The form and movement of clouds should be observed at different hours, in different weather conditions, and in different seasons. These observations should be made with a horizontal mirror, fitted with a bar and graduated scale. They lead to the following problems : —

a. The typical cloud forms and their changes (Davis, 177–179).

b. The prevailing direction and average velocity of cloud movements for different periods and especially for different weather conditions. Lower and upper clouds should be separated in this study (Davis, 119, 172, 181, 182).

c. Correlation of cloud form and movement with surface winds, with cyclones and anticyclones, and with weather changes (Davis, 213, 219, 228).

d. The use of clouds as weather prognostics (Davis, 330).

V. PRECIPITATION.

(Instructions, 43–49. Davis, 285–291.)

The quantity and rate of precipitation of various kinds should be measured by gauge during storms in different seasons. These observations lead to the following problems : —

a. The relation of precipitation in general to the other weather elements, and to cyclones and anticyclones of the weather maps (Davis, 287, 293, 300).

b. The conditions under which special forms of precipitation (rain, snow, sleet, hail, frozen rain) occur (Davis, 285–287).

c. The conditions associated with light and heavy, brief and prolonged, local and general rainfall (Davis, 248, 300).

VI. PRESSURE.

(Instructions, 30–42. Davis, 82–86.)

The variations of atmospheric pressure, although insensible to non-instrumental observation, are so intimately connected with atmospheric processes that they deserve careful attention. Their observation leads to several problems: —

a. The decrease of pressure with height, as between valley and hill; or between base and top of a building (Davis, 87, 88).

b. The diurnal and cyclonic variation of pressure in different seasons (Davis, 85, 86, 215, 316–318).

c. The relation of local pressure changes to cyclones and anti-cyclones, and thus to weather changes (Davis, 228, 316–318).

VII. WEATHER MAPS.

(Davis, 319–325.)

The use of the weather maps in connection with the problems of the preceding sections should have fully established the correlation between local and general conditions of temperature, pressure, wind, and weather. Under the present heading, practice should be given chiefly in: —

a. The construction of weather maps.

b. Weather prediction by means of weather maps, either used alone, or supplemented by local observations (Davis, 324).

General Remarks.

A review of the seven preceding headings will show that a very general correlation exists among them, whereby the subjects of every heading are associated with those of nearly every other. In other words, every weather element is treated as a function of several other elements. It follows from this that the variety of work here outlined is more apparent than real, and that many problems which appear from their wording to be entirely new are in large part re-arrangements of problems previously encountered. A review is therefore less necessary at the end of such a course as this than it might be in a course where the last heading was entirely unconnected with the first.

NON-OBSERVATIONAL WORK.

The non-observational or text-book portion of the course should supplement the observational work. It is intended to present the larger and more general principles of meteorology, which cannot be gained through local observation, but which serve to show the correlation of the various local phenomena with their fellows elsewhere over the world. As in the previous division of the course, much must necessarily be left to the teacher, both as regards the selection and order of additional subjects presented, and as regards the illustration of these subjects; but an essential for the satisfactory extension of the course under the present heading is that the topics here introduced should have been first encountered more or less directly in the problems of local observation.

In the following pages, reference is made to appropriate chapters of the text-book; but it is not expected that the text will be closely adhered to, or that it will be possible in every case to make the course as full as is here suggested.

Composition of the Atmosphere, and its Relations to Plants and Animals (Davis, Elementary Meteorology, Chap. I).

In the didactic presentation of a science, where the order of subjects has little relation to the questions asked by the pupils, this subject usually stands at the beginning of the course. In the text-book supplement to an observational course, it should be introduced only after questions concerning it have been raised by the pupils. The expert teacher will have little difficulty in directing the observational work in such a manner that the questions shall be called forth at any convenient stage of progress.

Extent and Arrangement of the Atmosphere about the Earth (Chap. II).

This topic may suggestively follow the determination of the decrease of atmospheric pressure with increase of altitude. Observations of shooting stars may here be referred to, and by correspondence with another school about a hundred miles distant, rough determinations of the height of the November meteors (November 13) may easily be made.

Control of Atmospheric Temperatures by the Sun. — The relation of the sun and earth, as determining the distribution of insolation over the earth, and its variations in time and place; the action of insolation on air, water, and land; the general idea of vertical temperature gradients, of local convectional circulation, and (briefly) of adiabatic changes of temperature in vertical currents (Chap. III).

A few questions concerning the change in the sun's noon altitude, in the direction of its rising and setting, and in the length of the day on successive dates will suggest the advisability of constructing a diagram of the earth's orbit in true proportions. A small globe moved around the orbit in proper position will lead to a clear understanding of the changes of the seasons, etc. This should be frequently referred to during the passage of the school year.

In association with the various observations on temperature, a number of simple physical experiments may be introduced, illustrating reflection, transmission, absorption, conduction, convection; all these being repetitions or extensions of experiments previously made in a course on Physics. Diagrams of diurnal and cyclonic temperature ranges and of vertical temperature gradients from various localities should be introduced as a natural sequence of the results determined by local observation.

General Distribution of Temperature over the Earth. — Systematic irregularities of isothermal lines; effects of ocean currents on the course of isotherms; thermal anomalies; annual ranges of temperature on land and water (Chap. V, omitting sections 73–80).

These subjects naturally follow the determination of the mean temperature of a day, of a period of days, and of successive periods. Exchange of records between schools standing on or near the same parallel or the same meridian will prove suggestive, both in awakening and in answering questions. After the establishment of this course for a few years, the comparison of current records with those of previous years will be instructive.

The General Circulation of the Atmosphere. — The general movement of the lower winds in different zones and different seasons; with a brief statement of the convectional theory of atmospheric circulation (Chap. VI, omitting sections 93–95, 98–108, 111–113, 116–123, 128, 131, and the greater part of Chap. VII).

The prevailing movement of the upper air currents from the west over all parts of the United States will be detected after a few weeks of observation. The determination of the prevailing westerly source of the surface winds will generally require a little longer interval. These two facts suffice to introduce a description of the prevailing directions of atmospheric movement in other parts of the world, thus quickly leading to their systematic classification. It is important that the explanation of the general circulation of the atmosphere, as modified by the earth's rotation, should be touched upon lightly, as its real nature is too difficult for elementary presentation. The wind belts, their migration, and their modification by continental interruptions, offer plentiful material for this part of the course.

Humidity, Dew, Frost, and Clouds. — The moisture of the atmosphere; evaporation, absolute and relative humidity, dew point, condensation on solid or liquid surfaces or in the air; classification of clouds (Chap. VIII, omitting sections 174–176; Chap. IX, omitting sections 191, 192, 198).

A variety of physical experiments illustrative of the evaporation and condensation may be here introduced. Observations during a few successions of fair and cloudy days will serve to arouse all the questions here needed. The geographical distribution of these topics is considered under later headings.

Storms. — Cyclones and Anticyclones and their Associated Winds; Thunderstorms and Tornadoes (Chap. X, omitting sections 239, 247; Chap XI).

The correlation of local observation with the winds charted on weather maps will suffice to introduce the greater part of these topics; the text-book may then supply fuller information about the circulation of winds in cyclones and anticyclones, the occurrence and paths of cyclones in various parts of the world, their relation to the general circulation, the peculiar winds associated with them, etc. An account of local storms may be introduced after a thunderstorm ordinarily observed in the later months of the school year; or if then wanting, the newspaper reports of local storms during the spring may be utilized to introduce these topics: their explanation may then be briefly treated.

Causes and Distribution of Rainfall (Chap. XIII): — The correlation of rainfall with stormy disturbances and with the general

circulation of the atmosphere gives the best clue to its general distribution and seasonal variation over the world.

Weather and Weather Prediction (Chap. XIII) : — Throughout the whole of the observational work, there will be abundant opportunity of introducing various topics under this heading. The variable weather characteristic of nearly every part of the United States should be compared with the similarly variable weather of certain other regions, and contrasted with the more uniform weather of the greater part of the torrid zone and of certain sub-tropical sea-coasts.

Climate (Chap. XIV) : — The succession of the seasons and the distribution of various kinds of weather through the year leads naturally to a study of those recurrent atmospheric conditions which constitute climate. The climates of various zones and regions may then be introduced as like or unlike our own climate. Here the dependence of human opportunities upon atmospheric controls is best introduced, although reference to this important subject may be made in connection with various earlier headings.